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ORIGINAL RESEARCH ARTICLE

Experimental studies of the acoustic and mechanical properties (compression) of materials made from industrial waste

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ABSTRACT

Noise negatively impacts human health and the environment, making it a pressing issue in the context of industrial development and urbanization. The objectives of this research include the production of durable panels from waste materials with gypsum as the binder, the study of their acoustic properties and sound absorption coefficient compared to traditional materials, as well as the analysis of mechanical properties and resistance to compressive forces. To conduct acoustic and mechanical studies, 36 special samples in the form of panels were manufactured from a mixture of gypsum with rubber and cork waste in various combinations, with the addition of polymer material and maintaining a specific water-to-powder ratio. Acoustic properties were determined using a device operating on the principle of "transmitter-receiver," while mechanical properties were assessed through compression testing. The results showed that all samples containing rubber and cork waste had a sound absorption coefficient higher than 0.35, which increased with frequency and decreased with increasing material density. An increase in the proportion of waste contributed to greater porosity and, consequently, improved sound absorption. Mechanical testing of the samples under compression demonstrated that their failure limit was reached at loads of up to 15 kN. Comparison with benchmark studies confirmed the effectiveness of utilizing recycled materials.

Keywords: Noise; industrial waste; tire waste; cork waste; sound insulation

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1. Introduction

One of the main negative factors affecting human health and the environment is noise. The progress in industrial development has posed the challenge for scientists to investigate ways to reduce noise levels to mitigate its harmful effects. Noise control can be achieved in two ways: monitoring noise sources, which, given the advancement of modern technologies, presents a quite complex task, and using sound barriers, that is, the effective application of sound-absorbing materials that significantly reduce the impact of sound exposure[1].

Scientists from many countries working on this issue have conducted numerous studies on the use of various industrial wastes to create materials with high sound-absorbing properties. American scientist Rafat[2] and his colleagues conducted experimental studies on the use of tire waste in various fields, the volume of which in the USA is approximately 3.6 million tons. Such fields include: rubber concrete, used for damping vibrations and countering impact loads on railways; rubber suspension prepared from rubber mixtures obtained by burning tires at a temperature of 850 °C for two hours, after which the collected ash is mixed in a ratio of 0-10% with sand. The results showed that the compressive strength and plasticity are higher than that of regular mortar; use as a filler for filling construction voids; application as a supporting material for bridge structures and trench filling.

In the studies[3], the possibility of enhancing thermal and sound efficiency through the use of ash and rubber waste from tires in traditional fiberglass building materials, which constitute over 80% of construction stone in North America, was examined. These materials not only improve the effectiveness of traditional insulation but also help eliminate waste that creates environmental problems.

Researcher[4] investigated the sound insulation properties of wood panels reinforced with rubber waste additives obtained from tire recycling. During the study, four samples were prepared: the first was a panel made of regular wood, the second was a panel made of compressed wood chips, the third was a panel made of a mixture of wood and rubber in a ratio of 40:60, and the last one was in a 50:50 ratio. The rubber waste consisted of cut particles ranging from 1 to 5 mm in size. The research found that the fourth sample outperformed the others in reducing sound penetration levels, achieving a reduction of 30 dB.

Researcher[5] also studied the physical, mechanical, thermal, and acoustic properties of materials obtained using various proportions of rubber waste from tires of different sizes (0-0.6; 0.5-2.5; 2.5-4 mm) combined with gypsum. The results confirmed positive changes in thermal, physical, and acoustic properties: with the addition of 50% particles, the density decreased to values (771.5; 891; 960 kg/m^3) depending on the sizes, while the thermal conductivity coefficient reduced to values (0.141; 0.152; 0.177 W/m·K) respectively. It turned out that the best acoustic properties belonged to the sample made of a mixture of rubber particles of 2 cm thickness with gypsum, which showed improved sound insulation. However, this negatively affected the compressive strength, which decreased from 23.23 N/mm^2 without additives to values (1.24; 1.38; 1.56 N/mm^2) for the samples with the other three sizes of rubber particles, respectively.

Researcher[6] studied the physical and mechanical properties of gypsum boards with the addition of waste rubber tube particles made from traditional insulation materials of various sizes (1-2, 2-4, 4-6, 20-25 mm) and proportions (12.5%, 25%, 50%, 75%). The results showed that the addition of 50% of 2-4 mm and 4-6 mm particles resulted in densities of 0.88 and 0.95 g/cm^3, respectively, while the compressive strength was 4.24 and 3.77 MPa. In contrast, the particles sized 20-25 mm provided a compressive strength of 0.97 MPa, which is considered below the 2 MPa threshold according to the UNE-EN 13279 standard and does not meet the requirements.

Researchers[7] experimentally determined the sound absorption coefficients for two types of rubber technical waste from tires: with fibers and without. Furthermore, it was proven that adding rubber to ordinary concrete reduces its density due to increased porosity and enhances the sound absorption coefficient. The sound absorption coefficient of fiber-reinforced concrete was 0.37, while for concrete with rubber particles without fibers, it did not exceed 0.25.

Researcher[8] utilized the properties of rubber derived from tires to produce sound insulation material based on polyurethane and rubber waste. The rubber particles contributed to vibration dampening, and when rubber was added in amounts ranging from 0% to 30%, the sound absorption coefficient reached values from 0.62 to 0.89 at a frequency of 2000 Hz, and from 0.70 to 0.91 at a frequency of 5000 Hz.

Research[9] focused on studying the impact of tire rubber waste with particle sizes of 2-4 mm on mechanical properties such as compressive strength and elasticity. The results indicated an increase in elasticity and a decrease in compressive resistance. However, treating these waste materials with synthetic resins before use for insulation purposes can improve compressive strength by 12% and elasticity by 40%.

Researcher[10] studied examined the thermal and acoustic properties of concrete made from recycled rubber aggregates. The results showed that the use of rubber aggregates improves thermal insulation and reduces sound transmission compared to traditional concrete. The study also indicated that recycled concrete possesses acceptable mechanical properties, making it a sustainable and effective option in construction applications. The findings suggest the potential use of these materials in enhancing the environmental performance of buildings.

Researchers[11] studied examined the mechanical properties of cement concrete containing recycled rubber. The results showed that the use of rubber pieces improves flexibility and reduces the overall weight of the concrete, enhancing its performance in construction applications. The study also demonstrated the potential for using these materials to improve sustainability and reduce the environmental impact of the construction industry.

In research[12] studied during experiments to evaluate the effectiveness of these materials in reducing noise, the results showed that organic waste, such as food scraps and plant materials, can be effective in improving sound insulation properties. Noise levels were measured before and after using these materials, and the experiments demonstrated a significant reduction in sound levels. It was also found that using organic waste as insulating materials is not only environmentally beneficial but also provides a sustainable economic solution to the problem of noise pollution in urban areas.

Researcher[13] studied evaluating the acoustic and mechanical properties of rubber-modified concrete. Rubber concrete is used as an eco-friendly alternative, with recycled rubber particles incorporated to enhance performance. The results showed that the addition of rubber can lead to improvements in certain mechanical properties, but it may negatively affect others, such as strength. The concrete's ability to absorb sound was measured, revealing that rubber-modified concrete has an improved capacity to reduce noise compared to traditional concrete. The findings suggest the potential for using rubber-modified concrete in construction projects that require a combination of strength and sound insulation.

The relevance of this research lies in the potential for the reuse of certain industrial waste materials, such as rubber derived from used tires and cork generated from various manufacturing processes, to create sound-insulating material. The resulting material must meet minimum requirements for certain mechanical properties to demonstrate its applicability in various applications.

Research Objectives:

1. To manufacture durable panels from waste using gypsum as a binding material at minimal costs, allowing for the recycling of these wastes and their disposal without harming the environment.

2. To experimentally study the acoustic properties and determine the sound absorption coefficient through comparative analysis with the properties of traditional panels.

3. To investigate the mechanical properties of the samples and experimentally determine their resistance to compressive forces, followed by a comparison with traditional gypsum boards reinforced with cardboard.

2. Materials and methods

Rubber and cork waste materials were used for the research, from which samples in the form of panels were formed, suitable for measurements during acoustic and mechanical testing.

2.1. Sample preparation

Rubber waste was shredded into particles measuring 2-4 mm, as performed in most studies[3-9], while cork waste was manually ground. **Figure 1** shows the types of waste materials used.

Figure 1. Types of waste materials used: a) – rubber, b) – cork.

Rubber waste was mixed in various weight ratios (25%, 50%, 75%) with gypsum as the dry material, with the addition of 5% polyurethane of Saudi origin from a company (SABIC)with the following characteristics: white color, density of 1.1 g/cm³, and melting temperature of 190 °C. This was done in a fixed proportion for all samples to ensure better adhesion and bonding. The water-to-gypsum ratio (w/p) was set at 0.75 in accordance with the EN 13279-1 standard[14], which requires it to be in the range of 0.6 to 0.8. The proportions of cork waste were mixed by volume (25%, 50%, 75%) with gypsum as the dry material, with 5% polyurethane and a water-to-gypsum ratio of 0.75 w/p. To ensure homogeneity, the components were mixed for 10-15 minutes, after which the mixture was poured into a mold and dried under the following conditions: temperature - 30-35 °C, humidity - 40%, atmospheric pressure - 1 atmosphere, for no more than 7 days until completely dry.

A total of 36 samples were prepared for the studies, as shown in **Figure 2**:

- 9 samples with three different weight ratios of rubber (3 samples for each weight ratio);

- 9 samples with three different weight ratios of rubber and the addition of cardboard (3 samples for each weight ratio);

- 9 samples with three different volume ratios of cork waste (3 samples for each weight ratio);

- 9 samples with three different volume ratios of cork waste and the addition of cardboard (3 samples for each weight ratio).

Figure 2. Examples of samples made from various materials.

2.2. Acoustic properties

To determine the acoustic properties of the samples, a device for measuring the sound absorption coefficient was used (**Figure 3**), which operates on the principle of "transmitter-receiver" in accordance with ISO 10534-1[15]. This method is based on placing the sample between a sound transmitter and receiver, sending a sound wave with a specific energy, and then measuring the energy of the wave after it passes through the sample while scanning the necessary frequency range for analysis and obtaining the sound absorption coefficient.

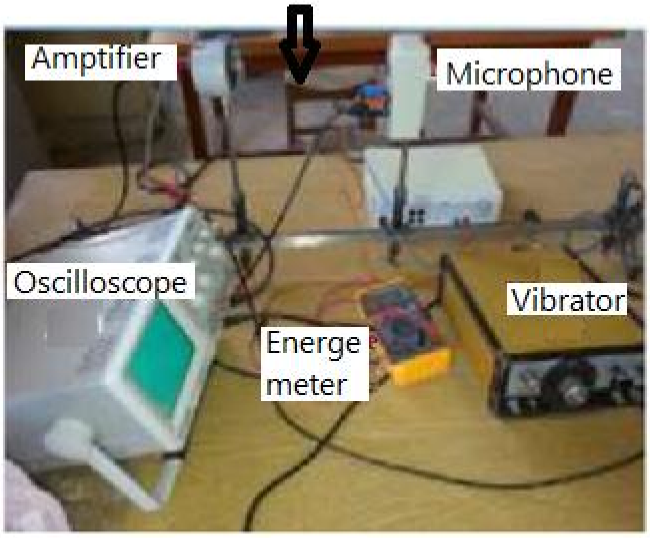

Figure 3. Device for measuring the sound absorption coefficient.

The device consists of a dual-channel electronic oscilloscope, a vibrator with a frequency range of (1-10 kHz), a carbon amplifier for transmitting sound waves, a microphone for receiving sound waves, two metal bases for mounting the amplifier and microphone, a one-meter bridge along which the amplifier and microphone slide, as well as an energy meter. Knowing the energy of the wave before and after the sample is installed, the sound absorption coefficient can be easily calculated, which is determined by the formula:

$$\alpha = \frac{E}{E_0}\,, \#(1)$$

где:

- α — Sound absorption coefficient;

- E — energy of the wave after the sample is installed, measured in volts;

- E_0 — energy of the wave before the sample is installed, measured in volts.

2.3. Mechanical properties (compression)

To determine the mechanical properties, a compression test was conducted using a universal mechanical testing machine (Testometric- United Kingdom) in accordance with ASTM 1012[16]. This device operates by applying axial compressive load to the test specimen through a moving head that presses down on the specimen, forming a compressive pair with a stationary lower head. The compressive force applied to the specimen increases over time, with the maximum design load that the device can apply being 200 kN. The rate of load application can be controlled through the device settings, which range from 0.01 to 500 mm per minute (see **Figure 4**). For data collection, the device is connected to a computer using specialized software, allowing for direct reading and printing of all results related to the tests conducted on the specimens, such as the values of applied stresses and strains, as well as the relationship between them, represented by the engineering stress-strain curve and other mechanical results.

To obtain the true stress curve, the following relationships are applied:

$$\sigma_{real} = \sigma(1-\varepsilon)\,, \#(2)$$

$$\varepsilon_{real} = \{\ln(1-\varepsilon)\}\,, \#(3)$$

где:

- σ — value of engineering stress, MPa;

- σ_{real} — value of true stress, MPa;

- ε — value of engineering strain;

- ε_{real} — value of true strain.

Figure 4. Device for compressive strength testing.

3. Research results

3.1. Results of acoustic properties determination:

Experimental results of the samples at various frequencies were obtained, and the energy values before and after placing the sample were recorded. **Table 1** shows the average values for 3 samples for each weight ratio of the additives. The sound absorption coefficient was calculated using formula (1) for all frequency values. The graph corresponding to one of the frequencies, specifically 3000 Hz, shows the dependence of the sound absorption coefficient on the proportion of rubber and cork waste, as illustrated in **Figure 5**.

Table 1. Energy at frequencies before and after placing the sample.

№	Waste content, %	Density, g/cm^3	Energy before placing the sample	Absorbed energy as a function of frequency, Hz				
				2000	2500	3000	3500	4000
			Gypsum with cork waste					
1	0	2.3	0,6	0,225	0,24	0,245	0,255	0,26
2	25	1.715		0,31	0,322	0,33	0,345	0,35
3	50	1.19		0,32	0,325	0,34	0,355	0,36
4	75	0.665		0,322	0,335	0,344	0,36	0,365
			Gypsum with cork waste and cardboard addition					
1/1	0	2.3	0,6	0,23	0,245	0,25	0,265	0,27
2/1	25	0.932		0,32	0,33	0,345	0,36	0,37
3/1	50	0.816		0,325	0,34	0,35	0,365	0,38
4/1	70	1.41		0,33	0,345	0,355	0,37	0,39
			Gypsum with rubber waste					
1/2	0	2.3	0,6	0,225	0,24	0,245	0,255	0,26
2/2	25	1.98		0,385	0,405	0,42	0,435	0,45
3/2	50	1.605		0,4	0,425	0,44	0,455	0,465

№	Waste content, %	Density, g/cm³	Energy before placing the sample	Absorbed energy as a function of frequency, Hz				
				2000	2500	3000	3500	4000
4/2	75	1.23		0,42	0,435	0,45	0,465	0,48
Gypsum with rubber waste and cardboard addition								
1/3	0	2.3	0,6	0,23	0,245	0,25	0,265	0,27
2/3	25	1.25		0,395	0,415	0,43	0,445	0,47
3/3	50	1.37		0,415	0,43	0,445	0,46	0,485
4/3	75	1.325		0,43	0,445	0,46	0,485	0,5

Table 1. *(continued)*

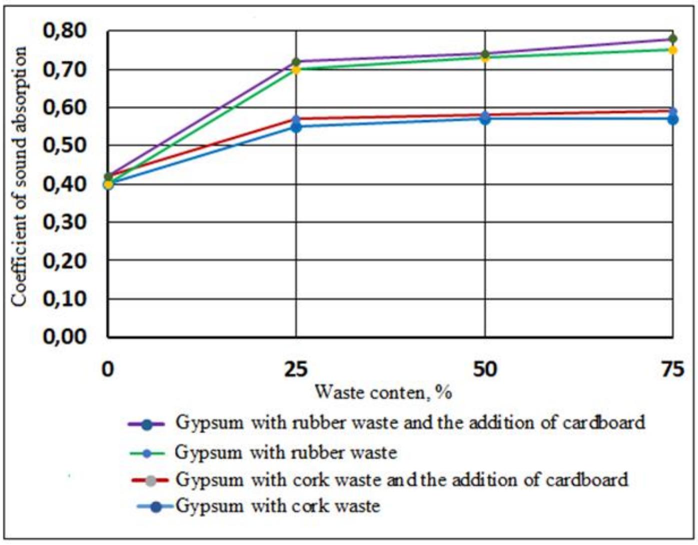

Figure 5. Change in sound absorption coefficient as a function of waste content percentage.

The results showed that all samples have a sound absorption coefficient above 0.35, and according to ASTM C423[17], these samples are considered acceptable for use in sound insulation. It was also established that the sound absorption coefficient is proportional to frequency: it increases with its rise due to the decrease in wavelength, while being inversely proportional to density. The increase in the proportion of waste leads to a decrease in density since the specific weight of rubber and cork is lower than that of gypsum, which contributes to an increase in the sound absorption coefficient due to increased porosity.

By comparing the obtained results with reference studies[5, 8, 18], we found that all studies confirmed the effectiveness of rubber derived from tire waste and recycled cork in improving the sound absorption coefficient, despite differences in measurement methods. The results also showed a slight improvement in the sound absorption coefficient in samples containing cardboard waste, thanks to their sound transmission reduction properties, as indicated in[19]. In comparison with traditional sound insulation materials, the average sound absorption coefficient for fiberglass was 0.85[3], and for polyurethane, it was 0.92[9].

3.2. Results of mechanical properties determination

To determine the mechanical properties, compression tests were conducted on square samples subjected to a load of up to 15 kN at a rate of 5 mm/min using a press machine. The program used for these purposes automatically generated deformation graphs and a true stress graph, considering the change in the cross-sectional area of the sample during testing until failure was reached. The values of true stress were calculated based on equations 2 and 3 to determine the actual compressive strength. The obtained results are presented in **Table 2** and **Figure 6**.

Table 2. Actual compressive strength.

№	Waste content, %	Density, g/cm³	Thickness, mm	Sample area, mm²	Maximum compressive stress, MPa
Gypsum with cork waste					
G	0	2.3			2
1F	25	1.715	20	2500	1,6
2F	50	1.19			1,1
3F		0.665			0,8
Gypsum with cork waste and cardboard addition					
GB	0	2.3			3,2
1f	25	0.932	20	2500	2,4
2f	50	0.816			1,5
3f	75	1.41			1
Gypsum with rubber waste					
G	0	2.3			2
1F	25	1.98	20	2500	2,7
2F	50	1.605			2,3
3F	75	1.23			1,85
Gypsum with rubber waste and cardboard addition					
GB	0	2.3			3,2
1f	25	1.25	20	2500	4,4
2f	50	1.37			3,8
3f	75	1.325			2,9

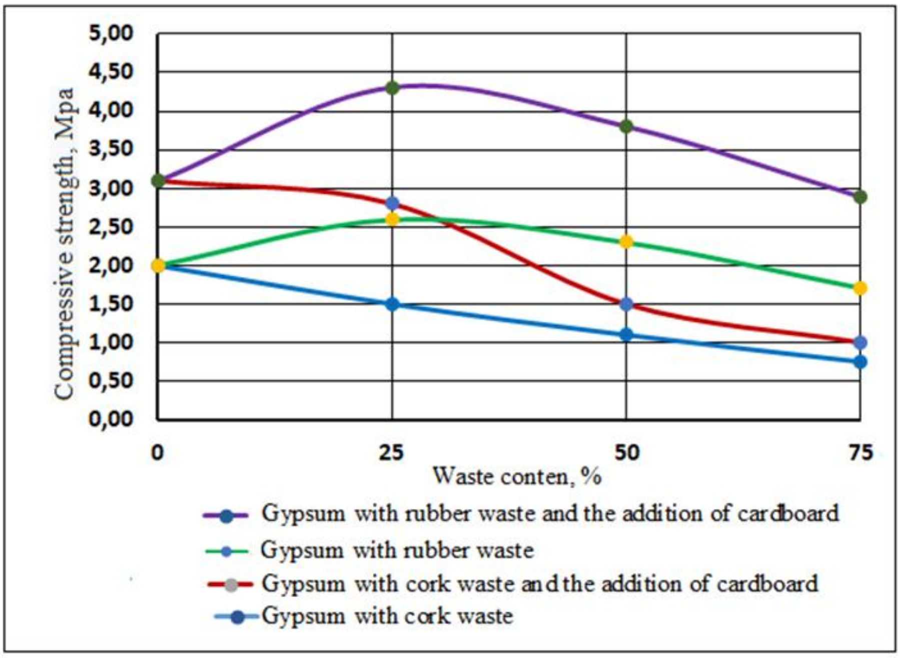

Figure 6. Change in compressive strength depending on the percentage of waste content.

Considering the results in **Table 2**, it can be observed that most rubber waste samples achieved compressive strength values above 2 MPa, and therefore meet the standards according to UNE-EN[10]. It was also found that as the proportion of waste increased, the resistance to compressive forces decreased, which is attributed to weak bonding and adhesion in the samples. Comparing the results with similar data from previous studies[5,6], a slight difference was noted, which can be explained by the variation in experimental conditions and the materials used.

As for the samples made from cork waste, a significant decrease in compressive strength was observed. This is due to cork being a lightweight and flexible material that contains air pockets, leading to reduced density and increased brittleness. It also has a lower load-bearing capacity compared to gypsum. This decrease has intensified with an increase in waste content, making the mixture more brittle, which reduces the effectiveness of load distribution throughout the material and leads to weaknesses in the composition, thereby decreasing compressive strength. However, when compared to[15], the results showed a significant similarity in values. Regarding the addition of cardboard to cork waste, the results demonstrated a clear positive effect on compressive strength, thus this additive can be considered a means to improve the weak compressive resistance.

4. Discussion and conclusion

This study conducted an experimental assessment of the acoustic and mechanical properties (compressive forces) of two of the most harmful industrial wastes that could become effective sound insulation materials in the future. These properties were determined through experiments on prepared samples, the results of which can be evaluated as follows:

1. In terms of acoustic properties, the samples based on rubber waste performed better than those based on cork waste. The sound absorption coefficient of the former increased with the rising percentage of waste, reaching a maximum value at 75%. Despite this, all samples demonstrated a sufficiently high degree of sound absorption, allowing for the use of both types of waste in the field of sound insulation.

2. In studies determining mechanical properties, a significant positive effect was identified from adding cardboard to gypsum in combination with waste. Samples based on rubber waste at a ratio of 25.5% showed greater resistance to compressive forces than samples made from pure gypsum with the addition of cardboard, while the resistance of samples based on cork waste was low. However, it is recommended to use cork waste in construction to reinforce walls and in studios, provided it remains protected from external weather effects. Therefore, the arguments related to the reuse of the mentioned types of waste, from an environmental and energy perspective, remain relevant for exploring their potential as materials for sound insulation and thermal insulation in the future.

The use of industrial waste in construction represents a significant opportunity to achieve sustainable development and reduce environmental impact, while providing potential economic benefits. It is important to support this trend through research and development, as well as the application of appropriate standards to ensure quality and durability.

Conflict of interest

The authors declare no conflict of interest.

References

1. Mohammad Ghofrani, Acoustical properties of plywood waste tire rubber composite panels. Measurement. 94, 2016, 382-387. https://doi.org/10.1016/j.measurement.2016.08.020
2. Rafat Siddique. Properties of concrete containing scraptire rubber – an overview. Waste Management, 24 ,2004, 563–569. https://doi.org/10.1016/j.wasman.2004.01.006
3. J.W. van de Lindt. Application and feasibility of coal fly ash and scrap tire fiber as wood wall insulation supplements in residential buildings. Conservation and Recycling ,52,2008, 1235–1240.
DOI: 10.1016/j.resconrec.2008.07.004
4. J. Zhao. Sound insulation property of wood–waste tire rubber composite. Composites Science and Technology, 70 , 2010, 2033–2038.
DOI: 10.1016/j.compscitech.2010.03.015

5. S. Herrero. Influence of proportion and particle size gradation of rubber from end-of-life tires on mechanical, thermal and acoustic properties of plaster–rubber mortars. Materials and Design ,47,2013, 633–642.
DOI: 10.1016/j.matdes.2012.12.063
6. 6. Ana Jiménez Rivero. New composite gypsum plaster –ground waste rubber coming from pipe foam insulation. Construction and Building Materials ,55, 2014, 146–152.
https://doi.org/10.1016/j.conbuildmat.2014.01.027
7. Nelson Flores Medina. Influence of fibers partially coated with rubber from tire recycling as aggregate on the acoustical properties of rubberized concrete. Construction and Building Materials.129, 2016, 25-36
https://doi.org/10.1016/j.conbuildmat.2016.11.007
8. G. Soto. Biobased porous acoustical absorbers made from polyurethane and waste tire particles. Polymer Testing, 57, 2016
DOI: 10.1016/j.polymertesting.2016.11.010
9. Yubo Jiao. Experimental Investigation of the Mechanical and Durability Properties of Crumb Rubber Concrete. MPDI,Materials, 9(3). 2016, 172
https://doi.org/10.3390/ma9030172
10. Junqiang Wang, Bin Du. Experimental studies of thermal and acoustic properties of recycled aggregate crumb rubber concrete. Journal of Building Engineering 32(12):101836, 2020.
DOI:10.1016/j.jobe.2020.101836
11. H. Alperen Bulut, Ufuk Kandil. Mechanical properties of cement-based composites incorporating eco-friendly aggregate of waste rubber. Revista de la Construcción, Vol. 23 (2), 2024.
https://doi.org/10.7764/RDLC.23.2.246
12. Hatice Mehtap Buluklu, Filiz Bal Kocyigit, Ercan Kose. Organic Waste as a Soundproofng Material: An Experimental Study. Journal of Vibration Engineering & Technologies, 12, 2024, 8043–8065
https://doi.org/10.1007/s42417-024-01344-w
13. Hassan Amer Algaifi and others. Assessment of acoustic and mechanical properties in modified rubberized concrete. Case Studies in Construction Materials, Volume 20, July 2024, e03063.
https://doi.org/10.1016/j.cscm.2024.e03063
14. UNE EN-13279-1, 2009. Gypsum binders and gypsum plasters- Part 1: Definitions and requirements.
15. International Organization for Standardization, ISO10534-2:1998. Acoustics– determination of sound absorption coefficient andimpedance in impedance tubes – Part 1: Method using standing wave ratio.
16. ASTM E1012-Standard Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application.
17. ASTM Standard C423, Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method.
18. F. Asdrubali. Insulation materials for the building sector: A review and comparative analysis. Renewable and Sustainable Energy Reviews, 62, 2016, 988–1011.
DOI: 10.1016/j.rser.2016.05.045
19. B. A. Kaya. Thermal and Mechanical Properties of Concretes with Styropor. Journal of Applied Mathematics and Physics, 02(06), 2014, 310-315. DOI: 10.4236/jamp.2014.26037